NASA/CR—2003-212005/PART11

Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites

Express/T-160E Project Express A2 and A3 Data Agreement Document

N. Sitnikova, D. Volkov, I. Maximov, and V. Petrusevich
Nauchno-Proizvodstvennoe Obiedinenie Prikladnoi Mekhaniki, Krasnoyarsk region, Russia

D. Allen
Schafer Corporation, Chelmsford, Massachusetts

June 2003

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at 301–621–0134

- Telephone the NASA Access Help Desk at 301–621–0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/CR—2003-212005/PART11

Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites

Express/T-160E Project Express A2 and A3 Data Agreement Document

N. Sitnikova, D. Volkov, I. Maximov, and V. Petrusevich
Nauchno-Proizvodstvennoe Obiedinenie Prikladnoi Mekhaniki, Krasnoyarsk region, Russia

D. Allen
Schafer Corporation, Chelmsford, Massachusetts

Prepared under Contracts NAS3–99151 and NAS3–99204

National Aeronautics and
Space Administration

Glenn Research Center

June 2003

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

Available electronically at http://gltrs.grc.nasa.gov

Preface

This 12-part report documents the data obtained from various sensor measurements taken aboard the Russian Express-A2 and Express-A3 spacecraft in Geosynchronous Earth Orbit (GEO). These GEO communications satellites, which were designed and built by NPO Prikladnoy Mekhaniki (NPO PM) of Zheleznogorsk, Russia, utilize Hall thruster propulsion systems for north-south and east-west station-keeping and as of June 2002, were still operating at 80° E. and 11° W., respectively. Express-A2 was launched on March 12, 2000, while Express-A3 was launched on June 24, 2000. The diagnostic equipment from which these data were taken includes electric field strength sensors, ion current and energy sensors, and pressure sensors. The diagnostics and the Hall thruster propulsion systems are described in detail along with lists of tabular data from those diagnostics and propulsion system and other satellite systems.

Space Power, Inc., now part of Pratt & Whitney's Chemical Systems Division, under contract NAS3–99151 to the NASA Glenn Research Center, obtained these data over several periods from March 12, 2000, through September 30, 2001. Each of the 12 individual reports describe, in detail, the propulsion systems as well as the diagnostic sensors utilized.

Finally, parts 11 and 12 include the requirements to which NPO PM prepared and delivered these data.

Filename	Title
CR-2003-212005-PART1.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A2 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of March 12, 2000 to and Including June 15, 2000, Task 29
CR-2003-212005-PART2.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type B Sensors for "Express-A" Number 2 Satellite for the Period of March 12, 2000 to and Including June 15, 2000, Task 25
CR-2003-212005-PART3.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of June 24, 2000 to and Including September 30, 2000, Task 30
CR-2003-212005-PART4.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of June 24, 2000 to and Including September 30, 2000, Task 27A

Filename	Title
CR-2003-212005-PART5.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of October 1, 2000 to and Including December 31, 2000, Task 31
CR-2003-212005-PART6.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of October 1, 2000 to and Including December 31, 2000, Task 27B
CR-2003-212005-PART7.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of January 1, 2001 to and Including March 31, 2001, Task 32
CR-2003-212005-PART8.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of January 1, 2001 to and Including March 31, 2001, Task 27C
CR-2003-212005-PART9.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of July 1, 2001 to and Including September 30, 2001, Task 33
CR-2003-212005-PART10.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of July 1, 2001 to and Including September 30, 2001, Task 27D
CR-2003-212005-PART11.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Express/T-160E Project Express A2 and A3 Data Agreement Document
CR-2003-212005-PART12.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Express/T-160E Project Express A2 and A3 Sensors Operations Procedures Document

SIGNATURE PAGE

This is a controlled document. Any changes require the concurrence of the two Approving Officials listed below.

Prepared by: _____

D. Allen/Schafer Corp. Date

Date

Reviewed by: _____

V. Petrusevich/NPO-PM Date

Approved by: _____

A. Romashko/NPO-PM Date

Approved by: _____

F. Elliott/GRC Date

DOCUMENTATION CHANGE PAGE

Document Title: Express/T160E Project Interface Control Document			
Change	**Description of Change**	**Date**	**Concurrence**
1	Initial Release	10/29/00	

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

A	Amps
DK	Pressure of Xenon Feed Unit output
DKR1	Pressure of primary Xenon Feed Branch
DKR2	Pressure of redundant Xenon Feed Branch
DVK	Pressure of Xenon Feed Unit input
EWSK	East-West Station Keeping
GRC	NASA Glenn Research Center
Hn	Heater number "n"
HETS	Hall Effect Thruster System
I	Current
NASA	National Aeronautics and Space Administration
NSSK	North-South Station Keeping
PPU	Power Processing Unit
PRD	Pressure regulation device
PS	Propulsion System
PV	Pyrotechnic Valve
RT	Redundant Thruster
RV	Reducing Valve
SA	Solar Array
SAn	Solar Array Panel number "n"
SPI	Space Power, Incorporated
SPT-100	Stationary Plasma Thruster with 100 mm discharge chamber diameter
T	Thruster
T18R	Temperature 1 of the Cylindrical Radiator
T19R	Temperature 2 of the Cylindrical Radiator
T1PK	Temperature of Xenon Feed Unit
T1SA	Temperature of Solar Array Panel number 1
T28K	Temperature of the Pressurized Container Surface
T2SA	Temperature of Solar Array Panel number 2
TBHKn	Temperature of Xenon Storage Unit number "n"
TBKn	Temperature of Thruster number "n"
TUn	Thruster Unit number "n"
US	United States
V	Voltage, Volts
Vn	Valve number "n"
XFU	Xenon Feed Unit
XSUn	Xenon Storage Unit number "n"

1.0 Purpose

The Express A2 and A3 Data Agreement Document describes and jointly approves the data to be provided from the Express A2 and A3 SPT-100 propulsion system and from other spacecraft subsystems. This document includes experiment objectives, a definition of each organization's roles and responsibilities for the data collection, reduction, and analysis, and the approach to be used to evaluate and distribute the obtained data. The data and analysis described in this document will be combined with data and analysis of sensor data described in a separate document (Express A2 and A3 Sensors Operations Procedures Document) to accomplish the overall Express/T160E project goals.

1.1. Background

The Express/T-160E project was initiated in March 1997 to develop a scaled-up, enhanced version of existing HETS technology in a North-South Station Keeping (NSSK) role on the Russian Express A3 communications satellite. The Express A satellites use SPT-100 thrusters for both NSSK and East-West Station Keeping (EWSK). On Express A3, we were going to use the T-160E HETS from this project instead of one of the onboard SPT-100 thrusters for part of the mission.

The majority of activity on the project was directed at developing, qualifying, and flight testing a 5.3 kW HETS including the T-160E Hall effect thruster and a modular Power Processing Unit (PPU). One of the primary goals of the project is to correlate thruster system performance testing on the ground with results obtained in space operations. In order to achieve this goal, the data collected during ground testing of HETS can be compared to data collected during the flight of that system on the Express A2 and A3 spacecraft.

The project also includes flight data collection from onboard sensors to measure plasma characteristics around the spacecraft. These sensors will be used on both the Express-A2 and A3 flights, complemented by ground tests of the sensors with Hall thrusters. The sensors will collect data periodically during the flights, when the thrusters are operating and when they are not being used. Data from the sensors, SPT-100 performance data, and other spacecraft subsystem data will be provided by NPO-PM to the project team for analysis and comparisons with ground-based test results.

1.2. Objectives for the Express A2 and A3 Data Acquisition and Analysis

The goals of this part of the Express/T160E project to be performed by the joint US/Russian team for the Express A2 and A3 flights can be summarized as follows:

- Acquire, reduce and analyze SPT-100 thruster system operation data
- Evaluate SPT-100 operation affects on the spacecraft on-board systems
- Develop a data base of SPT-100 use in orbit

2.0 Reference Documentation

Task 14 Completion Report, “Analyze data on the main types of operating SPT affects on satellite primary structure and on-board systems”, dated 1999.

Express A2 and A3 Sensors Operations Procedures Document (Draft) dated October 20, 2000

SPI subcontract No. 97-1088-02 for the Express/T160E Project with NPO PM, through Mod 13, dated 2000

3.0 Organization Roles and Responsibilities

This section is intended to describe the roles and responsibilities of each organization participating in the work on acquisition, reduction and analysis of SPT-100 and on-board systems operational data from the Express A2 and A3 satellites. GRC is the Express/T160E project sponsor. Both SPI and Schafer Corp. are under contract to GRC and will support data collection and analysis. NPO PM is under contract to SPI (subcontract under SPI's contracts with GRC) and will collect data from the spacecraft and provide it to GRC through SPI. NPO PM is also the Express A2 and A3 spacecraft integrator and is responsible for operating the spacecraft.

3.1. NASA Glenn Research Center

GRC is the lead organization for the Express/T-160E project. All work required to fulfill the requirements of this document will be performed by GRC personnel or by the other organizations listed below under contract to GRC. GRC will be the lead organization for the ground test portion of the project and will be responsible for comparing the flight data with the ground test data. GRC will also be responsible for distribution of data to organizations and people other than the project participants. Fred Elliott will be the GRC point of contact for data collection and analysis.

3.2. Space Power, Inc./Pratt and Whitney

SPI is the prime contractor for the Express/T-160E project. All work performed by NPO PM to accomplish the operations described in this document will be performed as part of NPO PM's subcontract with SPI. SPI will forward the data provided from the Express A2 and A3 spacecraft to GRC and Schafer. Kent Koester will be the SPI point of contact for data collection and analysis.

3.3. NPO PM

NPO PM will collect the required SPT-100 propulsion system and other spacecraft subsystem data from the Express A2 and A3 spacecraft and report the data to the Express/T-160E project in engineering units as described in this document. They will provide this data to the U.S. project participants through SPI in accordance with the terms of their subcontract from SPI. Victor Petrusevich will be the NPO PM point of contact for data collection and analysis.

3.4. Schafer Corp.

Schafer will review and analyze the NPO PM data for NASA and highlight any discrepancies requiring clarification from SPI and NPO PM. Schafer will provide GRC with the results of the data review and analysis. This will include data plots, identification of trends or anomalies, timeline integration of the sensor data with spacecraft subsystem data on plots to help understand any anomalies, and analysis of the data as it applies to potential use of HETS on US spacecraft. Doug Allen will be the Schafer point of contact for data collection and analysis.

4.0 Data Collection

NPO PM will collect data on operation of the SPT-100 propulsion systems and on other spacecraft subsystems. This data will be used to help project participants understand the operation of SPT-100s and their effect on the spacecraft on-board systems and also to evaluate the sensor data.

4.1. Telemetry Data Delivery

NPO PM will provide information regarding operation of the SPT-100 HETS and the Express A2 and A3 on-board systems by sending reports to SPI in accordance with terms of the NPO PM contract with SPI. Electronic files of the reports will be sent to SPI, GRC and Schafer.

4.2. Commands

The list of PS and PPU control commands with a description of functions that will be performed are given in the table below:

Command definition	Command action
Channel "plus Y"	1. Channel "plus Y" TU1 is prepared for switching on 2. PPU PRD circuit is powered
Channel "minus Y"	1. Channel "minus Y" TU2 is prepared for switching on 2. PPU PRD circuit is powered
Channel "plus Z"	1. Channel "plus Z" TU3 is prepared for switching on 2. PPU PRD circuit is powered
Channel "minus Z"	1. Channel "minus Z" TU4 is prepared for switching on 2. PPU PRD circuit is powered
T preparation	1. Selected channel primary thruster is prepared for switching on 2. Discharge voltage is fed to selected channel primary thruster 3. Receipt of primary thruster current protection operation is canceled
RT preparation	1. Selected channel redundant thruster is prepared for switching on 2. Discharge voltage is fed to selected channel redundant thruster 3. Receipt of redundant thruster current protection operation is canceled
C1 preparation	1. Selected thruster first cathode filament is switched on 2. Thermo-throttle corresponding to cathode starts to operate in alert mode
C2 preparation	1. Selected thruster second cathode filament is switched on 2. Thermo-throttle corresponding to cathode starts to operate in alert mode
XSU1 PV popping	XSU1 pyrotechnic valves are popped
XSU2 PV popping	XSU2 pyrotechnic valves are popped
T (RT) valves opening	Prepared thruster valves is open
Ignition	Voltage is fed to igniter
RV1 opening	1. Reducing valve (RV1) is open 2. Reducing valve (RV2) is closed 3. PRD is connected to XFU V1, V2 control. XFU V3, V4 are disconnected from control
RV2 opening	1. Reducing valve (RV2) is open 2. Reducing valve (RV1) is closed 3. PRD is connected to XFU V3, V4 control. XFU V1, V2 are disconnected from control
RV closing	RV1, RV2 valves are closed
T switching off	1. Discharge voltage is switched off from primary and redundant thrusters 2. Cathode filament circuits are switched off 3. Primary and redundant thrusters valves are closed 4. Primary and redundant thrusters thermo-throttles are switched off 5. Receipt of primary and redundant thrusters current protection operation is canceled

Command definition	Command action
	6. Channel selection is canceled 7. PPU initial state is reset
RT switching off	1. Discharge voltage is switched off from redundant thruster 2. Redundant thruster cathode filament circuits are switched off 3. Redundant thruster valves are closed 4. Redundant thruster thermo-throttles are switched off 5. Receipt of redundant thruster current protection operation is canceled
C switching off	1. Cathode filament is switched off 2. Ignition voltage is switched off 3. Thermo-throttle is switched to discharge current regulation mode
Thruster valves closing	Selected channel thrusters open valves are closed
Relief	Selected channel thrusters valves are opened
TU1 H1 switching on	TU1 H1 is switched on
TU1 H2 switching on	TU1 H2 is switched on
TU1 H switching off	TU1 H1, H2 are switched off
TU2 H1 switching on	TU2 H1 is switched on
TU2 H2 switching on	TU2 H2 is switched on
TU2 H switching off	TU2 H1, H2 are switched off
TU3 H1 switching on	TU3 H1 is switched on
TU3 H2 switching on	TU3 H2 is switched on
TU3 H switching off	TU3 H1, H2 are switched off
TU4 H1 switching on	TU4 H1 is switched on
TU4 H2 switching on	TU4 H2 is switched on
TU4 H switching off	TU4 H1, H2 are switched off
XFU H1 switching on	XFU H1 is switched on
XFU H2 switching on	XFU H2 is switched on
XFU H switching off	XFU H1, H2 are switched off

4.3. Data collection and data report formats

Data are collected from the SPT-100 HETS and other spacecraft subsystems during Express A2 and A3 spacecraft operation. NPO PM will prepare these data and deliver it to the US project participants in accordance with the terms of the NPO PM subcontract with SPI. Data will be reported for the period of 12 March 2000 to and including 15 June 2000 for Express A2 and the following time periods for Express A3:

- 24 June 2000 to and Including 30 September 2000
- 01 October 2000 to and Including 31 December 2000
- 01 January 2001 to and Including 31 March 2001
- 01 July 2001 to and Including 30 September 2001.

NPO PM will prepare these data and deliver it to the US program participants in accordance Section 4.1 above. The data report formats are provided below.

4.3.1. Data report forms for Task #29 and #30 of the NPO-PM sub-contract with SPI

NPO PM will provide the following data from the operations for the Express A2 and A3 SPT-100 HETS and other spacecraft subsystems for the first 3 months of each spacecraft's operations.

A) Propulsion System Configuration for the Express A Satellites

NPO PM will provide a description of the configuration of the Orbit Control Propulsion Subsystems for the EXPRESS-A. NPO PM will include a description of the differences between the use conditions for the Express-A and GALS Orbit Control Propulsion Subsystems. The use of HETS on GALS was described in NPO PM's Task 14 report. The

description will include propellant mass, allocation layout for the SPT-100 Thrusters with respect to center of gravity of the spacecraft, and ground test results on the SPT-100 HETS for Express A2 and A3. Ground test results will include thrust acceptance values for every thruster and anode current and anode voltage values when the thrust was measured. Xenon flow rate and tank pressure for these measurements will not be included because NPO PM does not have this information. The description will also include the specific locations on the spacecraft for each of the measurements (temperature, pressure, etc.) to be provided under sections 4.3.1 and 4.3.2 of this document.

B) Orbit Control Propulsion performance for EXPRESS-A2 (A3) after its injection into orbit.

The initial temperatures for the Orbit Control Propulsion Units and pressure in the Propellant Feed Subsystem following spacecraft separation from the launch vehicle upper stage will be provided as shown in the table formats below.

Location	Xe Storage Unit 1	Xe Storage Unit 2	Xe Storage Unit 3	Xe Feed Unit	Thruster Unit 1	Thruster Unit 2	Thruster Unit 3	Thruster Unit 4
	Temperature (°C)							
Value								

Location	Xe Feed Unit Output	Primary Xe Feed Branch	Redundant Xe Feed Branch
	Pressure (kgf/cm^2)		
Value			

C) Initial Setup of the Orbit Control Propulsion system

NPO PM will describe the Evacuation of Orbit Control Propulsion Pipelines on Express A2 (A3) including the time and date of execution and the command sequence using the table format shown.

Command	Time of execution

The pressure change at the XFU Output (Parameter DK) and the pressure in the Main and Redundant Xenon Feed Branches (Parameters DKR1 and DKR2) during evacuation of Propulsion cavities (on available telemetry sessions) will be provided using the following table format:

Time (hh:min:sec)							
Xe Feed Unit Output Pressure (kgf/cm^2)							
Primary Xe Feed Branch Pressure (kgf/cm^2)							
Redundant Xe Feed Branch Pressure (kgf/cm^2)							

Data will be provided for pressurizing the Orbit Control Propulsion system with Xenon. This will include the pressure change at the XFU Output (Parameter DK) and at the XFU Input (Parameter DVK). It will also include the pressure in the Main and Redundant Xenon Feed Branches (Parameters DKR1 and DKR2) during pressurization of the propulsion pipelines (on available telemetry sessions) as well as the time the command was issued as shown below:

Command	Time of execution (hh:min:sec)	Xe Feed Unit Output	Xe Feed Unit Input	Primary Xe Feed Branch	Redundant Xe Feed Branch
		Pressure (kgf/cm^2)			

D) Propulsion system conditions after completion of Initial Setup:

The following data will be provided to describe the condition of the HETS before the first thruster firing, including relevant HETS temperatures and pressures.

Location	Xe Storage Unit 1	Xe Storage Unit 2	Xe Storage Unit 3	Xe Feed Unit	Thruster Unit 1	Thruster Unit 2	Thruster Unit 3	Thruster Unit 4
	Temperature (°C)							
Value								

Location	Xe Feed Unit Output	Xe Feed Unit Input	Primary Xe Feed Branch	Redundant Xe Feed Branch
	Pressure (kgf/cm^2)			
Value				

E) Test Firing SPT-100 Orbit Control Thrusters

The following data will be provided to describe the initial test firing of the SPT-100 HETS including the date of execution and Test Firing Data based on TM-data processing results from the initial 32 Firing Events:

Thruster No	Cathode No	Time, of execution hh:min:sec	Command	Parameters									
				Anode Voltage, V	Anode Current, A	Xe Storage Unit 1 Temp. °C	Xe Storage Unit 2 Temp. °C	Xe Storage Unit 3 Temp. °C	Xe Feed Unit Temp. °C	Thruster Unit 1 Temp. °C	Thruster Unit 2 Temp. °C	Thruster Unit 3 Temp. °C	Thruster Unit 4 Temp. °C
XXX	XX	XX:XX:XX	Select Channel XX	XXX,X	X,X								
		XX:XX:XX	Thruster preparation	(parameters are given at the instant of command issue and further at a time of each change)									
		XX:XX:XX	Cathode preparation										
		XX:XX:XX	Opening Thruster Valves										
		XX:XX:XX	Ignition	XXX,X	X,X								
		XX:XX:XX	Cathode switching off	XXX,X	X,X								
		XX:XX:XX	Thruster switching off	XXX,X	X,X								
XXX	XX	XX:XX:XX	Select Channel XX	XXX,X	X,X								
…	…	…	…	…	…								

Conclusions will also be provided regarding the serviceability of thrusters based on the test firings.

F) Temperature Variation for the Orbit Control Propulsion Units

NPO PM will provide temperature change plots based on data obtained at an interval of 30 minutes during a day for each Orbit Control Propulsion Unit. Work execution date and time will be included in hh:mm:ss (one day during March 2000 – for Express A2, June 2000 – for Express A3).

G) Functioning SPT-100 thruster data

The executed tasks will be listed. The Total Thruster Operating Time will be provided in a table with total operating time for every thruster on each cathode in terms of duration and number of firings for the period reported.

Thruster No	Cathode No	Firing Duration	Firing Number

The total number of firings will be provided with information regarding each firing in the form of a table:

Date	Thruster No	Cathode No	Operation Time

H) Telemetry Data for the Start-up and Operation of Thrusters during drift (transfer) into a final satellite station point.

The available telemetry will be provided in the following table formats.

H.1) Firing Commands Table:

Command	Time of execution			Comments
	No 1	No 2	No 3	

H.2) Telemetry Data Table:

Time	Thruster No.	Cathode No.	Cathode Current, A	Anode Current, A	Anode Voltage, V	Xe Feed Unit Pressure (kgf/cm2)	Comments

H.3) Temperature change of SPT-100 Orbit Control Propulsion system

NPO PM will provide a temperature change plot of available TM-data for the SPT-100 Orbit Control Propulsion system.

I) Start-up and operation of thrusters for performing station keeping operations

NPO PM will provide data from at least 3 firings per month in the following table formats:

I.1) List of firing commands:

Command	Time of execution			Comments
	No 1	No 2	No 3	

I.2) Data on each thruster firing:

Time	Thruster No	Cathode No	Cathode Current, A	Anode Current, A	Anode Voltage, V	Xe Feed Unit Pressure (kgf/cm 2)	Comments

Notes: 1) Data are given with an interval of 30 sec to 60 sec.
2) Additionally, the table will include the temperature of operating thruster (TBKn), temperatures of Xenon Storage Units (TBHK1, TBHK2, TBHK3), temperature of Xenon Feed Unit (T1PK), pressure at input of Xenon Feed Unit (DVK), pressure in main and redundant Xenon Feed Lines (DKR1 and DKR2), and pressure of the xenon feed unit output (DK).

J) Thrust based on ranging results during East-West and North-South maneuvers.

Thrust in the East-West direction will be calculated and provided by NPO PM for the orbit control thrusters which are operated during drift and transfer phases. NPO PM will include a description of the method used to calculate the thrust and the uncertainty of the value calculated.

For the North-South orbit control thrusters, mean-integral values of effective thrust (taking into account a loss of thrust due to an interaction with the spacecraft structure) based on the measurements between the 14 days and 28 days cycles of station keeping will be provided by NPO PM. This is clarified as follows: spacecraft ranging is performed once a period of 14 to 28 days, of which there are 13 to 27 inclination control operations with different North-South thrusters.

K) Comments on SPT operation

NPO PM will provide comments on the operation as well as the measures taken to avoid problems.

L) Spacecraft On-Board System Data

NPO PM will provide the data described in sections M through R for the initial operations (first 3 months) of the Express A2 and A3 spacecraft. These data will be used to understand how the thrusters interact with the spacecraft and as a basis for comparison with later data to be obtained on the same subsystems to better understand long term effects of operating the thrusters on other spacecraft subsystems.

M) Power Supply Subsystem

NPO PM will provide a description of the configuration and a description of the solar array layout for the EXPRESS-A Power Supply Subsystem. This will include solar array measurements in a diagram format and a layout of the solar array panels with respect to spacecraft's center of gravity.

M.1) NPO PM will provide the following parameters of Power Supply Subsystem after the spacecraft reaches thermal equilibrium following injection into geostationary orbit, deployment of the solar arrays, and acquisition of the Sun:

T1SA – Temperature of SA 1
T2SA – Temperature of SA 2

The temperatures T1SA and T2SA are measured with an interval of 30 min to 60 min during a day and are represented in table form as shown below. Data will be provided for one day in March 2000 for express a2 and for one day in June 2000 for Express A3.

Date	Time	Solar Array Panel 1 Temperature, °C	Solar Array Panel 2 Temperature, °C

M.2) The following parameters of Power Supply Subsystem will be provided by NPO PM after the spacecraft is transferred into a mode of precise Sun orientation of the Solar Array:

I (SA1+SA2) – current from SA panels SA1 and SA2;
V (SA1+SA2) – voltage on output buses of SA1 and SA2;
I (SA3) – current from panel SA3;
V (SA3) – current from panel SA4;
I (SA4) – voltage on output buses of SA3;

V (SA4) – voltage on output buses of SA4;

The parameters I (SAi) and V(SAi) measured once a month are provided in the form of a table:

Date	Solar Array Panels 1 and 2		Solar Array Panel 3		Solar Array Panel 4	
	I, (A)	V, (V)	I, (A)	V, (V)	I, (A)	V, (V)

N) Attitude Determination And Control Subsystem:

There are disturbing torques caused by the SPT-100 Thrusters when they are operating. NPO PM will provide calculated values of the disturbing torques (x, y, and z) during the operation of the SPT-100 thrusters for at least two firings per month for North-South thrusters and for one firing of West-East thrusters (if a firing is performed). Values of the disturbing torques will be provided in the form of a table:

Thruster No	Cathode No	SA Angle (degree)	X disturbing Torque (N·m)	y disturbing Torque (N·m)	z disturbing Torque (N·m)

O) Attitude Control Propulsion:

NPO PM will provide propellant flow rate for the attitude control propulsion when operating SPT-100 thrusters. The magnitude of attitude control propulsion propellant mass used to compensate the disturbing torques when operating the SPT-100 thrusters will be calculated. Data will be provided for the SPT-100 firings where disturbing torques are determined.

P) Thermal Control Subsystem

NPO PM will provide locations for the temperature sensors on the pressurized container and the radiator. The following parameters are measured after the spacecraft is injected into geostationary orbit and reaches thermal equilibrium:

T18R – temperature of the cylindrical radiator;
T19R – temperature of the cylindrical radiator;
T28K – temperature of the pressurized container surface.

Parameters of the thermal control subsystem are measured with an interval of 30 min to 60 min during a day in March 2000 for EXPRESS-A #2 (a day in June 2000 for EXPRESS-A #3) and are provided in the form of a table:

Date	Time (hr:min:sec)	Cylindrical Radiator Temperature 1 (°C)	Cylindrical Radiator Temperature 2 (°C)	Pressurized Container Surface Temperature (°C)

Q) On-board navigation subsystem

NPO PM will provide the longitude of station point (degrees, minutes, and seconds) and an inclination (degrees, minutes, and seconds) for the spacecraft after each ranging session.

R) Communications Module

NPO PM will provide conclusions based on checkouts of coupled operation of transponders and SPT-100 stationary plasma thrusters. NPO PM will provide information

on the registered facts of anomalous telemetry data reception during the firing of the SPT-100 for the reporting time period.

4.3.2. Data report forms for Task #31, #32 and #33 of the NPO-PM sub-contract with SPI

NPO PM will provide the following data from the operations for the Express A3 SPT-100 HETS and other spacecraft subsystems.

A) Functioning SPT-100 thruster data

The executed tasks will be listed. The Total Thruster Operating Time will be provided in a table with total operating time for every thruster on each cathode. Data will be provided in terms of duration and number of firings for the period reported.

Thruster No	Cathode No	Firing Duration	Firing Number

The total number of firings will be provided with information regarding each firing in the following table format.

Date	Thruster No	Cathode No	Operation Time

B) Start-up and operation of thrusters for performing longitude/inclination station keeping

NPO PM will provide data from at least 3 firings per month including all thruster operations for which data is transmitted from the Express A3 satellite in the following table formats

B.1) List of firing commands

Command	Time of execution			Comments
	No 1	No 2	No 3	

B.2) Data on each thruster firing

Time	Thruster No	Cathode No	Cathode Current, A	Anode Current, A	Anode Voltage, V	Xe Feed Unit Pressure (kgf/cm2)	Comments

Notes: 1) Data are given with an interval of 30 to 60 sec.
2) Additionally, the table will include the temperature of the operating thruster (TBKi), the temperatures of the xenon Storage Units (TBHK1, TBHK2, TBHK3), the temperature of the xenon Feed Unit (T1PK), pressure at the input of the xenon Feed Unit (DVK), pressure in the main and redundant xenon Feed Lines (DKR1 and DKR2) and the pressure of the xenon Feed unit output (DK).

C) Thrust based on ranging results during East-West and North-South maneuvers.

Thrust in the East-West direction will be provided by NPO PM for the orbit control thrusters (provided if the thrust is determined).

For the North-South orbit control thrusters, mean-integral values of effective thrust (taking into account a loss of thrust due to an interaction with the spacecraft structure)

based on the measurements between the 14 days and 28 days cycles of station keeping will be provided by NPO PM.

D) Comments on SPT operation

NPO PM will provide comments on the thruster operation as well as the measures taken to avoid problems.

E) Power Supply Subsystem

The temperatures T1SA and T2SA are measured with an interval of 30 to 60 min during a day and are represented in table form as shown below. For Express A3 data will be provided for one day in September and December 2000, and in September 2001.

Date	Time (hh :mm : ss)	Solar Array Panel 1 Temperature, °C	Solar Array Panel 2 Temperature, °C

The parameters of current, I (SAi) and voltage, V (SAi) are measured once a month and are provided in the form of a table:

Date	Solar Array Panels 1 and 2		Solar Array Panel 3		Solar Array Panel 4	
	I, (A)	V, (V)	I, (A)	V, (V)	I, (A)	V, (V)

F) Attitude Determination and Control Subsystem:

NPO PM will provide calculated values of the disturbing torques (x, y, and z) during the operation of the SPT-100 thrusters for at least two firings per month for North-South thrusters and for one firing of West-East thrusters (if a firing is performed). Values of the disturbing torques will be provided in the form of a table:

Thruster No	Cathode No	SA Angle (degree)	x disturbing Torque (N·m)	y disturbing Torque (N·m)	z disturbing Torque (N·m)

G) Attitude Control Propulsion:

NPO PM will provide propellant flow rate for the attitude control propulsion when operating SPT-100 thrusters. The magnitude of attitude control propulsion propellant mass used to compensate the disturbing torques when operating the SPT-100 thrusters will be calculated. Data will be provided for the SPT-100 firings where disturbing torques are determined.

H) Thermal Control Subsystem

NPO PM will provide parameters of the thermal control subsystem which are measured with an interval of 30 min to 60 min during a day in September and December 2000 and March and September 2001. Data are provided in the form of a table:

Date	Time (hr:min:sec)	Cylindrical Radiator Temperature 1 (°C)	Cylindrical Radiator Temperature 2 (°C)	Pressurized Container Surface Temperature (°C)

I) On-board navigation subsystem

NPO PM will provide the longitude of station point (degrees, minutes, and seconds) and an inclination (degrees, minutes, and seconds) for the spacecraft after each ranging session including the time of the reading (hr:min:sec).

J) Communications Module

NPO PM will provide information on the registered facts of anomalous transponder operation and telemetric data reception during the firing of the SPT-100 for the reporting time period.

4.4. Timing of telemetry measurements

NPO PM will measure SPT-100 parameters, sensor parameters, and other spacecraft subsystem parameters as close together as possible. For example, it is important to understand cathode and anode current and voltage characteristics and spacecraft temperature measurements at the same time that readings are taken for the plasma sensors so that these measurements can be correlated.

5.0 Express A2 and A3 Mission Assessments

5.1. Express A2 and A3 Mission Analyses

The project participants may conduct analyses of data from the SPT-100 propulsion and other on-board systems of Express A2 and A3 satellites.

5.2. Reports

NPO PM will provide five reports with all of the required data, as specified in Section 4.3 of this document, in accordance with Tasks Number 29 through 33 of the subcontract with SPI. One report will be delivered following completion of each of the time periods listed in Section 4.3 above.

Schafer will provide five interim reports and one final report to GRC. The interim reports will be prepared following receipt of each of the five NPO PM spacecraft subsystem data reports. Schafer will be responsible for analyzing the data provided by NPO PM as it applies to US requirements and will provide a report on this review to GRC. Schafer will prepare a final report that summarizes all of the data from Express A2 and A3.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 2003	Final Contractor Report

4. TITLE AND SUBTITLE

Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites

Express/T-160E Project Express A2 and A3 Data Agreement Document

5. FUNDING NUMBERS

WBS–22–800–91–01
NAS3–99151
NAS3–99204

6. AUTHOR(S)

N. Sitnikova, D. Volkov, I. Maximov, V. Petrusevich, and D. Allen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Nauchno-Proizvodstvennoe Obiedinenie Prikladnoi Mekhaniki (NPO PM)
52 Lenin Street, Zheleznogorsk-2
Krasnoyarsk region, 662990, Russia

8. PERFORMING ORGANIZATION REPORT NUMBER

E–13691–11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR—2003-212005-PART11

11. SUPPLEMENTARY NOTES

N. Sitnikova, D. Volkov, I. Maximov, and V. Petrusevich, Nauchno-Proizvodstvennoe Obiedinenie Prikladnoi (NPO PM) 52 Lenin Street, Zheleznogorsk-2, Mekhaniki, Krasnoyarsk region, 662990, Russia. D. Allen, Schafer Corporation, 321 Billerca Road, Chelmsford, Massachusetts 01824–4191. Project Manager, John Dunning, Power and Propulsion Office, NASA Glenn Research Center, organization code 6900, 216–433–5298.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 20 Distribution: Nonstandard

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This 12-part report documents the data obtained from various sensor measurements taken aboard the Russian Express-A2 and Express-A3 spacecraft in Geosynchronous Earth Orbit (GEO). These GEO communications satellites, which were designed and built by NPO Prikladnoy Mekhaniki (NPO PM) of Zheleznogorsk, Russia, utilize Hall thruster propulsion systems for north-south and east-west stationkeeping and as of June 2002, were still operating at 80° E. and 11° W., respectively. Express-A2 was launched on March 12, 2000, while Express-A3 was launched on June 24, 2000. The diagnostic equipment from which these data were taken includes electric field strength sensors, ion current and energy sensors, and pressure sensors. The diagnostics and the Hall thruster propulsion systems are described in detail along with lists of tabular data from those diagnostics and propulsion system and other satellite systems. Space Power, Inc., now part of Pratt & Whitney's Chemical Systems Division, under contract NAS3–99151 to the NASA Glenn Research Center, obtained these data over several periods from March 12, 2000, through September 30, 2001. Each of the 12 individual reports describe, in detail, the propulsion systems as well as the diagnostic sensors utilized. Finally, parts 11 and 12 include the requirements to which NPO PM prepared and delivered these data.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Propulsion; Electric propulsion; Hall thrusters; Hall effect	27
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	